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Calculating Synergistic and Antagonistic Responses of Herbicide Combinations[1]

S. R. Colby[2]

Abstract. The responses of herbicides applied singly are used in calculating the "expected" response when they are combined. The expected response for a combination is obtained by taking the product of the percent-of-control values for herbicides applied alone and dividing by (100)ⁿ⁻¹ where n is the number of herbicides in the combination.

In spite of the tremendous increase in testing of herbicide combinations, the words "synergistic" and "antagonistic" have been largely avoided in publication of results. Uncertainty in determining "expected" responses for herbicide combinations may be partially responsible for the failure of workers to report synergism and antagonism. Another difficulty frequently encountered is that the herbicides used in combination are not applied singly in the same study. When herbicides have not been applied singly, there is no basis for predicting the response when they are applied in combination.

Several mathematical methods are available for testing the additivity of herbicide combinations (3, 6). This paper presents a method which facilitates calculating the "expected" responses of herbicide combinations. The "expected" response for a given combination of two herbicides can be calculated as follows (3, 5):

If X = the percent inhibition of growth by herbicide A at p lb/A

and Y = the percent inhibition of growth by herbicide B at q lb/A

and E = the expected percent inhibition of growth by herbicides A + B at p + q lb/A

then, according to Gowing (3):

$$E = X + \frac{Y(100-X)}{100} \qquad (I)$$

Algebraic manipulation of terms in equation I yields equation II, the form used by Limpel et al. (5):

$$E = X + Y - \frac{XY}{100} \qquad (II)$$

When the observed response is greater than expected, the combination is synergistic; when less than expected, it is antagonistic. If the observed and expected responses are equal, the combination is additive.

In the use of equation II, original units of data, such as weed counts or fresh or dry weights of plants, are converted to "percent inhibition" values. Once this is done, it is necessary to perform one addition, a subtraction, a multiplication, and one division to obtain each expected response (equation II).

If instead, we convert the original data to "percent-of-control" values, the number of arithmetic operations required to obtain "E" is reduced.

Let X_1 = growth as a percent-of-control with herbicide A at p lb/A

and Y_1 = growth as a percent-of-control with herbicide B at q lb/A

and E_1 = expected growth as a percent-of-control with herbicides A + B at p + q lb/A

then $E_1 = 100 - E$

$X_1 = 100 - X$

$Y_1 = 100 - Y$

hence $E_1 = 100 - (X + Y - \frac{XY}{100})$

and $E_1 = 100 - ((100 - X_1) + (100 - Y_1) - \frac{(100-X_1)(100-Y_1)}{100})$

finally $E_1 = \frac{X_1 Y_1}{100} \qquad (III)$

The use of formula III as compared with formula II eliminates the addition and subtraction, thus reducing the number of operations required to obtain an "expected" response.

Colby (2) extended formula I to apply to three-way combinations.

Thus, if Z = the percent inhibition of growth by herbicide C at r lb/A

then $E = X + Y + Z - \frac{(XY + XZ + YZ)}{100} + \frac{XYZ}{10,000} \qquad (IV)$

Now if Z_1 = growth as a percent-of-control with herbicide

then $E_1 = \dfrac{\dfrac{C a t r \, lb/A}{X_1 Y_1 Z_1}}{10,000}$ (V)

Obviously, the use of formula V instead of IV reduces the number of arithmetic operations required to obtain the expected response since the subtractions and additions are eliminated. In general, the expected response for any combination of herbicides may be obtained by taking the product of the percent-of-control values for herbicides applied alone and dividing by $(100)^{n-1}$ where n is the number of herbicides in the combination. Each herbicide must be applied singly at the same rate as used in combination.

Data published by Jagschitz and Skogley (4) are used to illustrate the calculation of expected responses for herbicide combinations. Four herbicides were applied singly and in certain combinations for the control of several weeds in turfgrass. The data as originally presented have been converted to percent-of-control values and are shown in Tables 1 and 2. Expected values for the combinations are shown in

Table 1. Dandelion control in fairway turf treated with various herbicides October 8, 1961.[a]

Herbicide	lb/A	Dandelion response, % of-control, 10-7-65[b]		
dicamba	0.125	55		
	0.25	25		
	0.5	43		
mecoprop	0.5	97		
	1.0	81		
	1.5	79		
2,4-D	0.5	63		
	1.0	54		
	1.5	44		
picloram	0.0625	40		
	0.25	10		
dicamba + mecoprop	0.125 + .5	51	(53)	+ 2
	0.125 + 1.0	33	(55)	+12
dicamba + 2,4-D	0.125 + 0.5	51	(35)	−16
	0.125 + 1.0	64	(30)	−34
	0.25 + 1.0	58	(14)	−44
	0.5 + 1.0	46	(23)	−23
mecoprop + 2,4-D	0.5 + 0.5	56	(61)	+ 5
	0.5 + 1.0	47	(53)	+ 5
	1.0 + 0.5	43	(51)	+ 8
	1.0 + 1.0	57	(44)	−13
	1.5 + 1.0	76	(43)	−33
dicamba + mecoprop + 2,4-D	0.125 + 0.5 + 0.5	63	(34)	−29
	0.125 + 1.0 + 0.5	31	(28)	− 3
	0.125 + 1.0 + 1.0	52	(29)	−23
	0.125 + 1.0 + 1.0	54	(24)	−30
dicamba + mecoprop + 2,4-D + picloram	0.125 + 0.5 + 0.5 + 0.0625	77	(13)	−64

[a]Adapted from the data of Jagschitz and Skogley (4).
[b]Expected responses for combinations are shown in parentheses following each observed response. The differences between observed and expected values also are shown by a plus sign to indicate synergism and a minus, antagonism.

parentheses following each observed value, the difference between observed and expected values is shown. A positive value is indicative of a synergistic response while a negative value is indicative of an antagonistic response. If the observed and expected values had been computed individually for each replication, then a chi-square test could have been used to de-

termine the statistical significance of the differences between observed and expected values. Even without the chi-square test, several conclusions seem probable from the data in Tables 1 and 2. First, the combinations appear antagonistic on dandelion. Furthermore, the antagonism seems to be greater with increasing combined rates, especially when the herbicides were applied in 1964. Possibly this antagonism is caused by greater contact injury or more plant tops being killed at higher rates resulting in less translocation of herbicide into the dandelion roots. It also appears from Table 2 that different weeds respond differently to the same

Table 2. Chickweed and dandelion control in fairway turf treated with various herbicides May 25, 1965.[a]

Herbicide	lb/A	Chickweed response, % of-control, 10-19-65[b]		Dandelion response, % of-control, 10-19-65[b]	
dicamba	0.125	40		46	
	0.25	1		53	
	0.5	0		49	
Mecoprop	0.5	16		87	
	1.0	0		62	
	1.5	0		72	
2,4-D	0.5	51		75	
	1.0	22		64	
	1.5	0		56	
dicamba + mecoprop	0.125 + .5	1	(6) + 5	70	(57) −13
	0.125 + 1.0	0	(0)	28	(41) +13
dicamba + 2,4-D	0.125 + .5	9	(20) +11	67	(50) −17
	0.125 + 1.0	3	(13) +10	41	(42) +21
	0.25 + 1.0	0	(0)	41	(34) − 7
	0.5 + 1.0	0	(0)	53	(31) −22
mecoprop + 2,4-D	0.5 + .5	1	(8) + 7	77	(65) −12
	0.5 + 1.0	1	(3) + 4	68	(56) −12
	1.0 + 0.5	1	(0) − 1	70	(47) −23
	1.0 + 1.0	1	(0) − 1	55	(40) −15
	1.5 + 1.0	0	(0) − 1	69	(46) −23
dicamba + mecoprop + 2,4-D	0.125 + 0.5 + 0.5	1	(2) + 2	57	(43) −14
	0.125 + 1.0 + 0.5	0	(0)	64	(31) −33
	0.125 + 0.5 + 1.0	0	(2) + 2	54	(37) −17
	0.125 + 1.0 + 1.0	0	(0)	29	(26) − 3

[a]Adapted from the data of Jagschitz and Skogley (4).
[b]Expected responses for combinations are shown in parentheses following each observed response. The differences between observed and expected values also are shown by a plus sign to indicate synergism and a minus, antagonism.

combination. Thus, combinations which were about additive or possibly synergistic on chickweed were antagonistic, in general, on dandelion.

The calculations involved in determining the expected response of one three-way combination from Table 1 illustrate the efficiency of formula V compared to formula IV. For example, using dicamba at 0.125 lb/A in combination with mecoprop at 0.5 lb/A and 2,4-D at 0.5 lb/A the expected response is calculated as follows using formula IV and the data in terms of percent weed control as originally reported by Jagschitz *et al.* (4).

$$E = 45 + 3 + 37 - \frac{(45(3) + 45(37) + 3(37))}{100}$$
$$+ \frac{(45)(3)(37)}{10,000}$$
$$= 85 \quad - \frac{(135 + 1665 + 111)}{100} + \frac{4995}{10,000}$$
$$= 85 \quad - 19.11 + 0.50$$
$$= 66.39\% \text{ weed control expected}$$

Using formula V and percent-of-control values, the computation is

$$E_t = \frac{(55)(97)(63)}{10,000}$$

= 33.61 percent-of-control

and 33.61%-of-control is equal to 66.39% weed control.

Obviously, there are practical limitations in using mathematical formulas in predicting the responses for herbicide combinations. The methods described here are approximations, but they represent an improvement over no attempt to predict responses. The computations described should most effectively be applied to populations of single species although this would not seem to be an absolute requirement. Furthermore, the formulas are most accurate when values of X, Y, and Z are near the 50% level since the dose-response curves deviate least from linearity at the 50% level.

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Seasonal Variation in Sprouting and Available Carbohydrate in Yellow Nutsedge Tubers[1]

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Abstract. Two morphological types of tubers of yellow nutsedge (*Cyperus esculentus* L.) were collected over a 2-year period and were sprouted in the laboratory. Tuber dormancy occurred during late summer and early fall. Sprouting was highest during the winter and spring. Mechanical disturbance of the nutsedge stand increased tuber sprouting. Available carbohydrates followed a pattern similar to sprouting: minimum levels were found during late summer. The two types of tubers appeared to be similar in respect to the characteristics studied.

INTRODUCTION

DORMANCY commonly occurs in various organs and at different seasons of the year among species of higher plants (7). Generally, little is known of dormancy in subterranean organs of weeds, including tubers of yellow nutsedge (*Cyperus esculentus* L.). Tumbleson and Kommedahl (6) indicated that tubers were dormant when dug in September but would germinate in June. Breaking of tuber dormancy was thought to be associated with low temperature and leachable inhibitors. Other research has dealt mainly with methods of breaking dormancy of tubers by chemical techniques (2). Control of yellow nutsedge with postemergence herbicides is partially dependent on tuber dormancy, since emergence of shoots must be optimum when the herbicides are applied for maximum effects.

Another factor often related to effectiveness of herbicides in the control of perennial weed species is the level of reserve carbohydrates. However, studies attempting to relate carbohydrate levels with herbicide susceptibility have not been clearly successful (4, 5).

In these studies, I have attempted to characterize tuber dormancy and carbohydrate content and their possible relation to herbicide utilization.

METHODS AND MATERIALS

A dense stand of yellow nutsedge growing in a field of Tifton loamy sand was the source of plant material. Samples were collected at monthly intervals from July, 1962 to June, 1964. During July, 1962 to June, 1963, samples were randomly collected over the infested area. The stand was not disturbed mechanically except for an early spring plowing and harrowing. During the months of July to November, 1963, the area was subdivided into 25 by 30 ft plots. Three twice-replicated treatments were imposed. One treatment was a continuation of the mechanically undisturbed stand mentioned above. Other treatments were (a) mowing approximately 2 weeks prior to the next sampling date and (b) disk-harrowing approximately 2 weeks prior to the next sampling date. At the conclusion of this sampling period, further collections were made only from the mechanically undisturbed plots.

At each sampling date, duplicate lots of approximately 500 tubers were recovered by working the soil through a coarse screen. On several occasions during 1963, unwashed tubers were recovered from mechanically undisturbed plot samples by searching the soil samples and brushing off most of the adhering soil from the tubers.

Except for the unwashed lots, the tubers were subjectively graded into four types according to external color and morphology, and then counted. Type A tubers were black-skinned, shriveled, and usually dead; type B were black but turgid; type C were brown and turgid;